Modeling and Predicting Driver Behavior in ACT-R

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Why Driving?

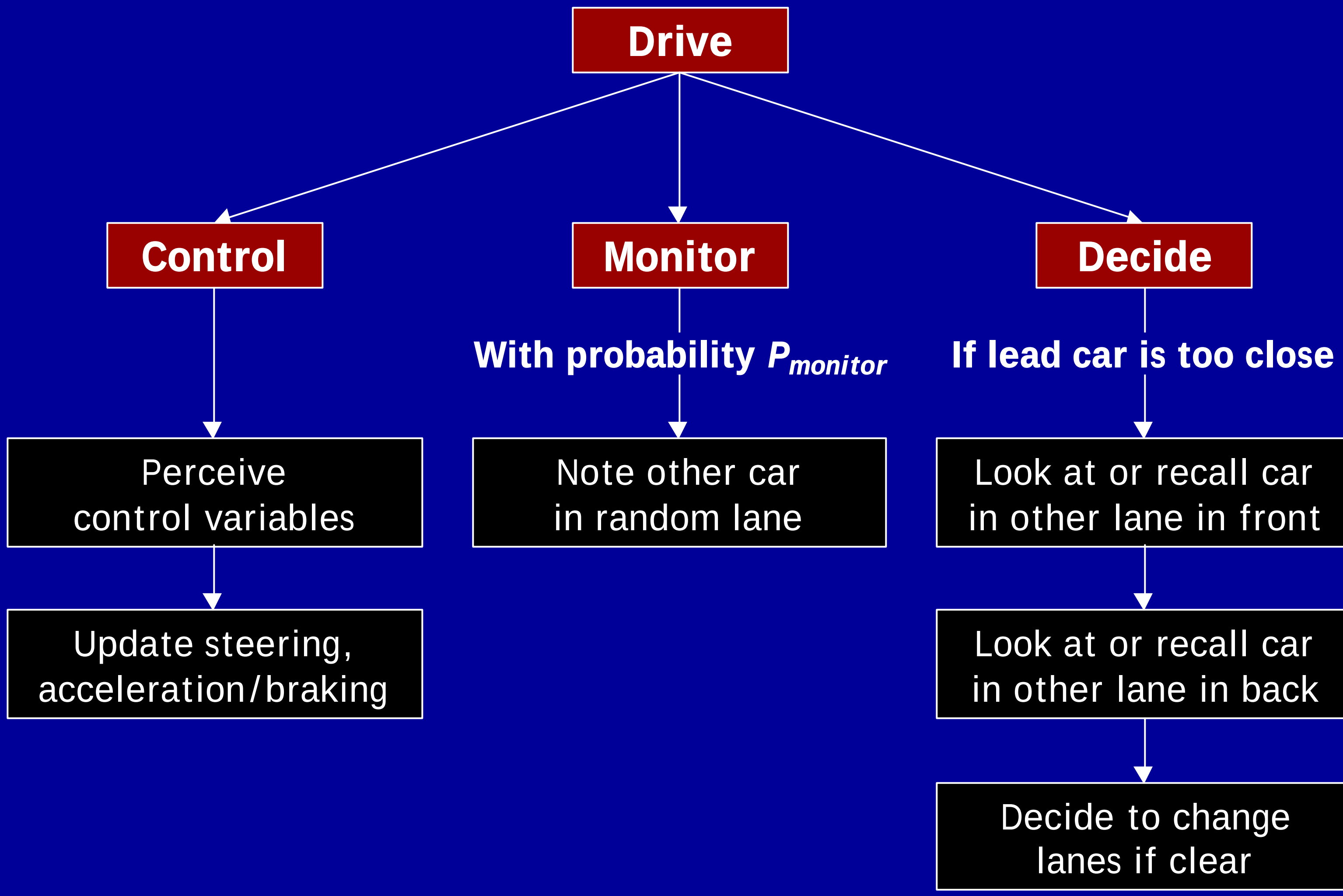
- Dynamic
- Continuous
- Time-critical
- Integrated
  - low-level control
  - high-level cognition

Modeling Driver Behavior

- *Goal*: Computational model of driver behavior
  - perception
  - control
  - task scheduling
  - decision making
  - navigation
  - planning …

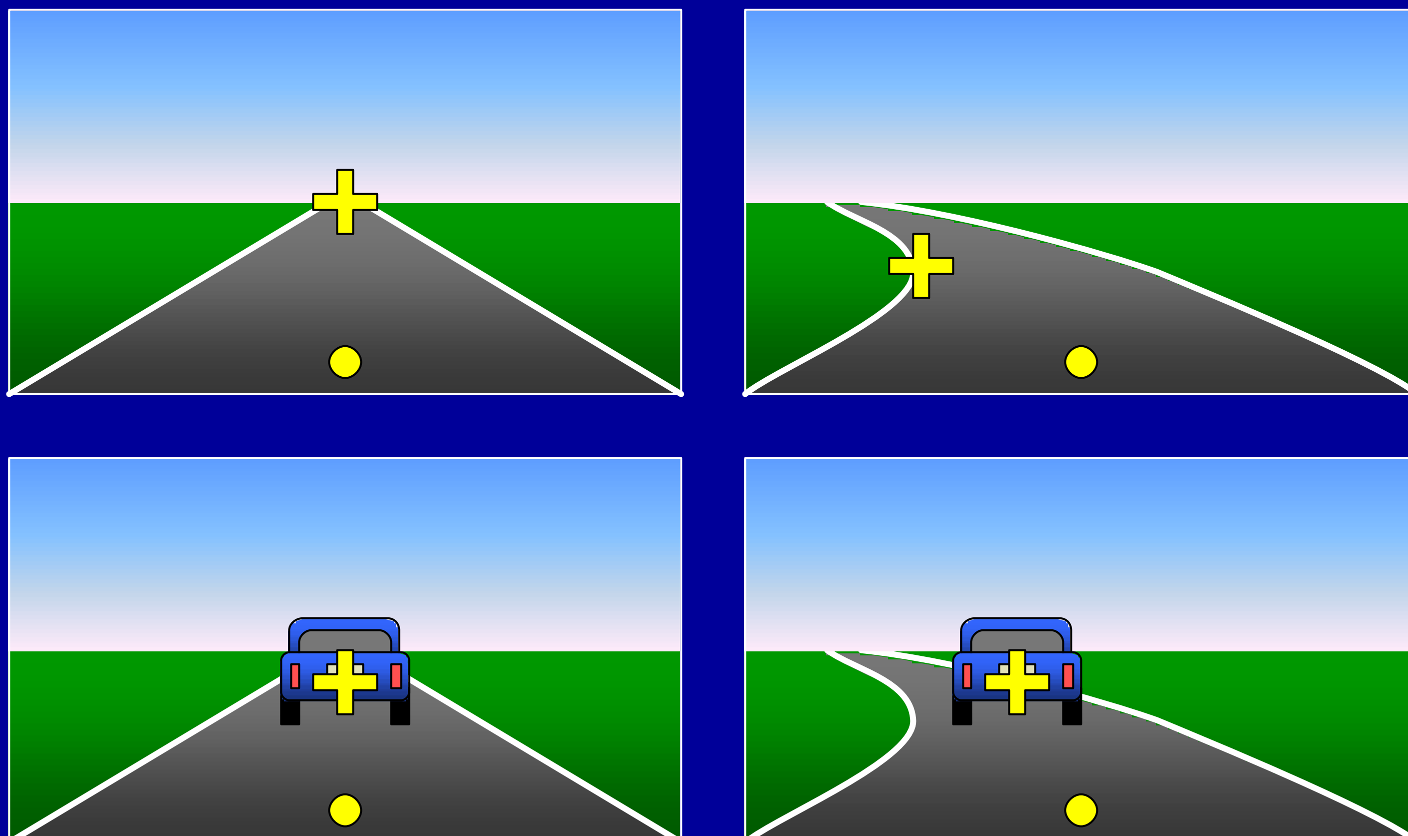
  that incorporates the "human element"
  - attention
  - cognition
  - motor response
  - multitasking
  - variability
  - emotions …
- The ACT-R Driver Model
  - cognition: ACT-R 4.0 (45 productions)
  - perception: RPM + EMMA
  - action: special routines

Driver Model Overview



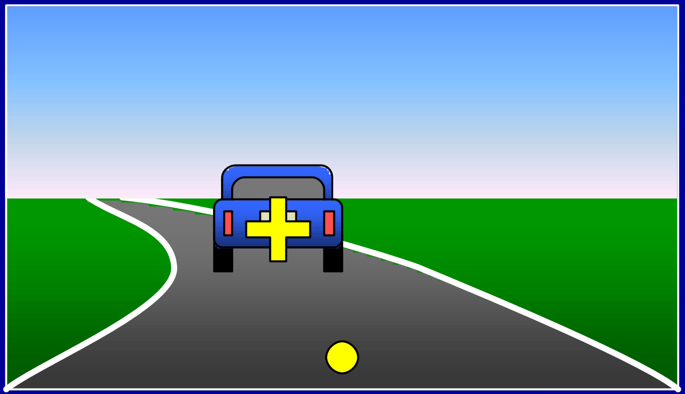
Control: Perception

- Two-level control with near, far points



Control: Perception

- Find near point θ
- Find far point θ
- Encode far point d, type
- Perceive t
- Compute $\Delta\theta$, Δt



Control: Perception

```
(p control-attend-far
  =goal>
    isa drive
    stage control-perceive
    lane =lane
    - na nil
    nloc =nloc
    fa nil
    floc nil
  =loc>
    isa visual-location
    time now
    kind far
    color =lane
    nearest =nloc
    screen-x =x
==>
  !send-command! :vision move-attention
                           :location =loc
  !bind! =a (image->angle =x)
  =goal>
    fa =a
    floc =loc)
```

```
(p control-encode-far
  =goal>
    isa drive
    stage control-perceive
    - na nil    - fa nil
    floc =loc v =v
    fval nil
    fkind nil
  =object>
    isa far
    screen-pos =loc
    kind =kind
    distance =d
    value =value
  =state> (free)
==>
  !bind! =time (pm-time)
  !bind! =thw (thw/ =d =v)
  =goal>
    stage control-steering
    fd =d
    fthw =thw
    fval =value
    fkind =kind
    time =time)
```

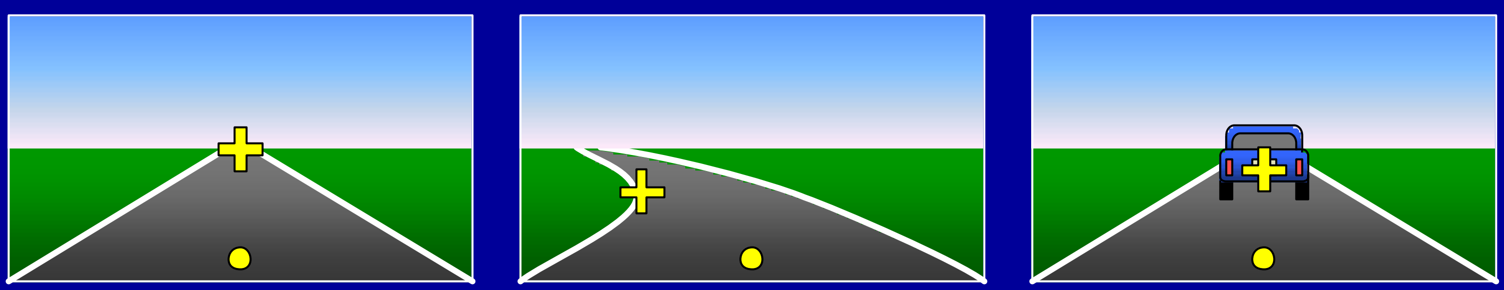
Control: Action

- Steering = $f\,(\Delta\theta_{far},\ \Delta\theta_{near},\ \theta_{near},\ \Delta t)$

$$\Delta steer = c_1(\Delta q_{far}) + c_2(\Delta q_{near}) + c_3(q_{near})\Delta t$$

- Acceleration = $f\,(\Delta THW_{car},\ THW_{car},\ \Delta t)$

$$\Delta acc = c_4(\Delta THW_{car}) + c_5(THW_{car} - THW_{follow})\Delta t$$

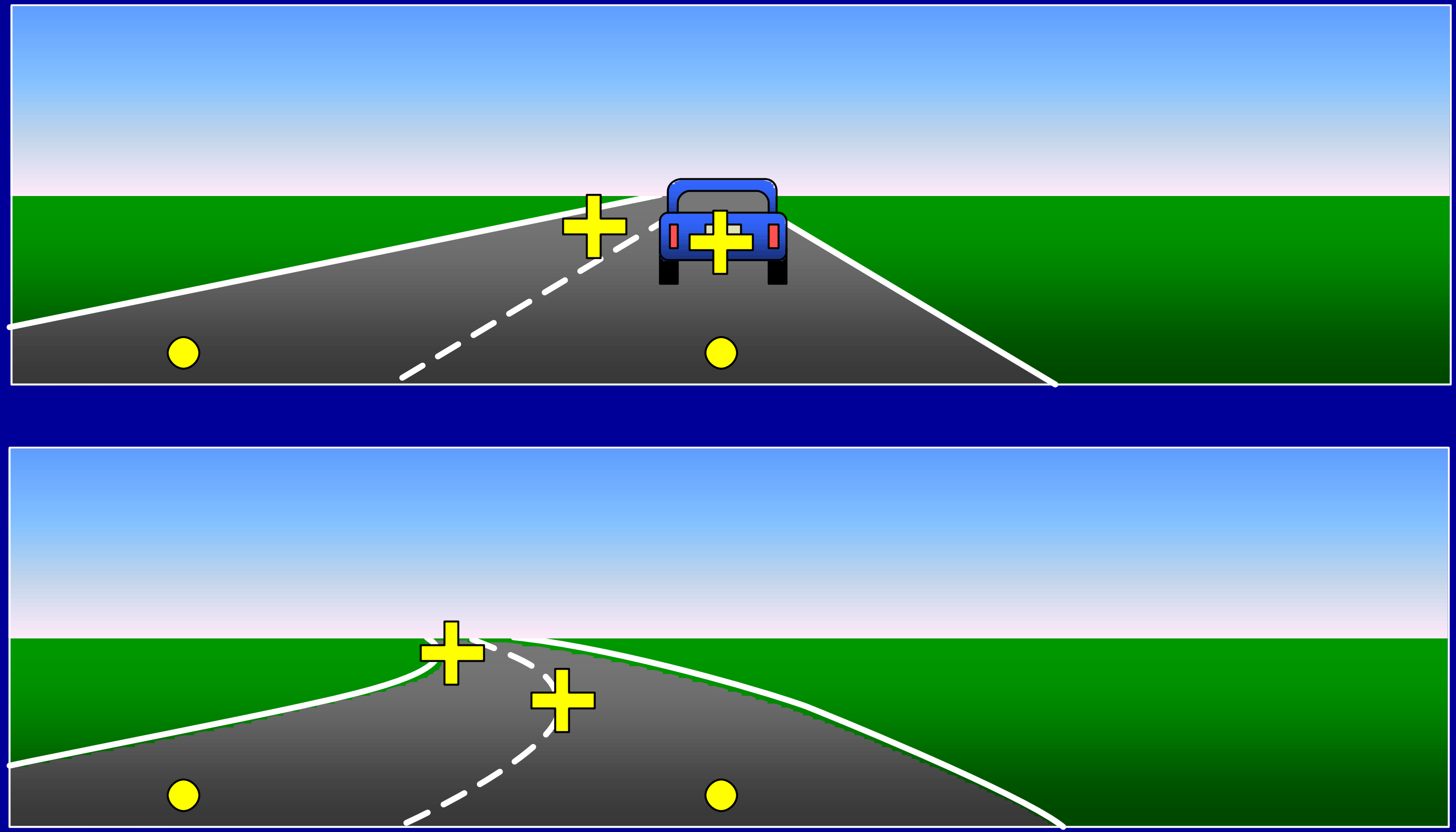


Control: Action

```
(p control-steering
  =goal>
    isa drive
    stage control-steering
    oldgoal =oldgoal
    na    =na
    fa    =fa
    time  =time
    fval  =fval
  =oldgoal>
    isa drive
    na    =na2
    fa    =fa2
    time  =time2
    fval  =fval
==>
  !eval! (let ((na =na)
               (dna (- =na =na2))
               (fa =fa)
               (dfa (- =fa =fa2))
               (dt (- =time =time2)))
           (do-steer na dna fa dfa dt))
  =goal>
    stage control-speed)
```

Control: Lane Changing

- Switch control from start → end lane



Monitoring

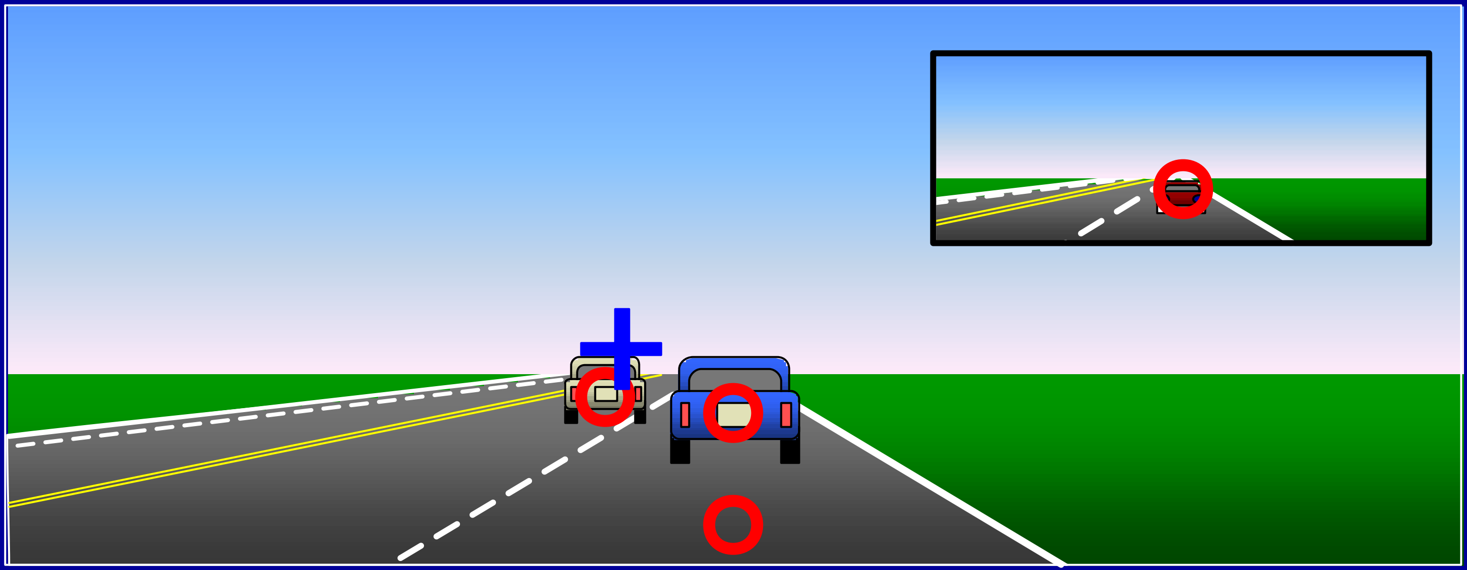
- With some probability (.33)
  - choose random lane (left/right)
  - choose random direction (front/back)
  - look for car in chosen lane/direction
  - if exists, note its location
- Thus, memory contains mental model of current situation

Decision Making

- If lane change is desired (THW < THW for passing)
  - look at or recall cars in other lane
    - uses mental model of environment
  - if no cars pose a danger, make decision to change lanes

Driver Model: Eye Movements

- EMMA: integrated model of eye movements and visual attention (Salvucci, in press)
  - spotlight of attention moves rapidly and often
  - eyes move only occasionally to focus of attention



Environment: Nissan CBR Simulator

Human Driver Replay

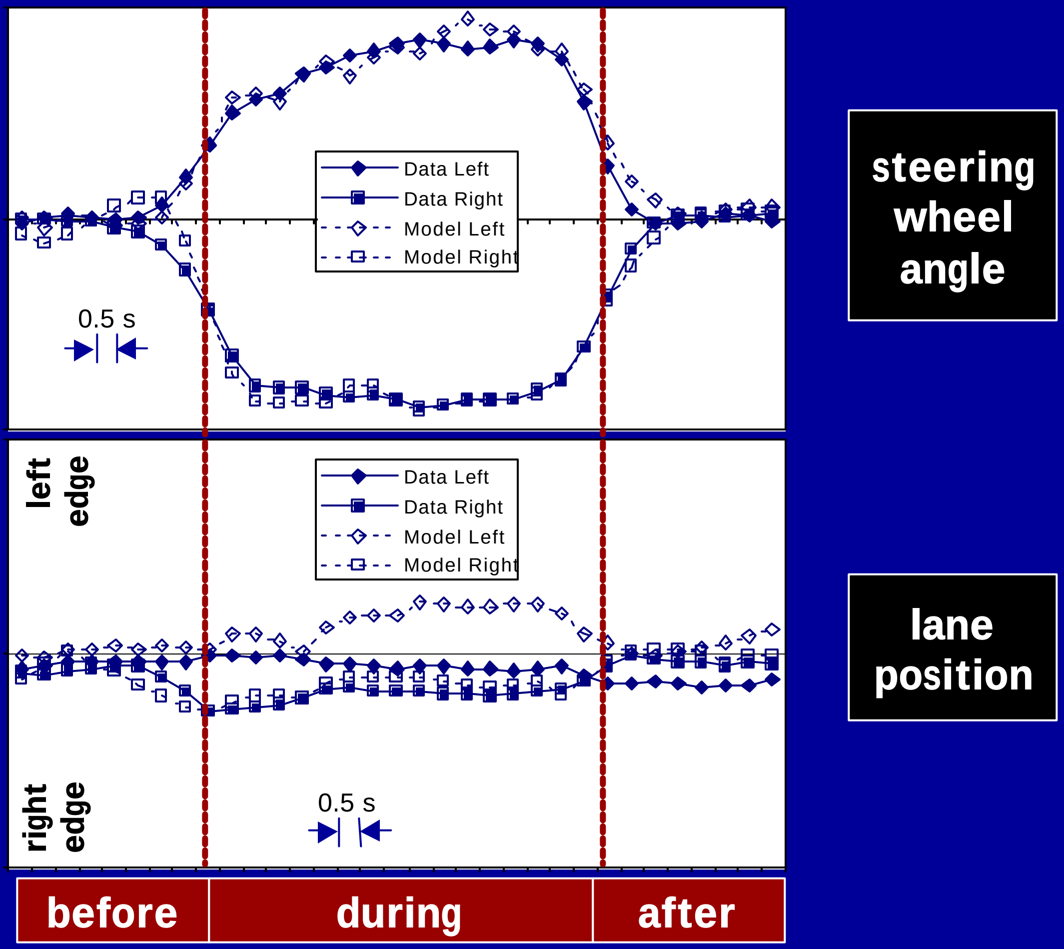
Model Replay

Model Results: A Sampling

- Steering & Curve negotiation
- Steering & Lane changing
- Attention & Lane keeping
- Effects of workload
- Ongoing work

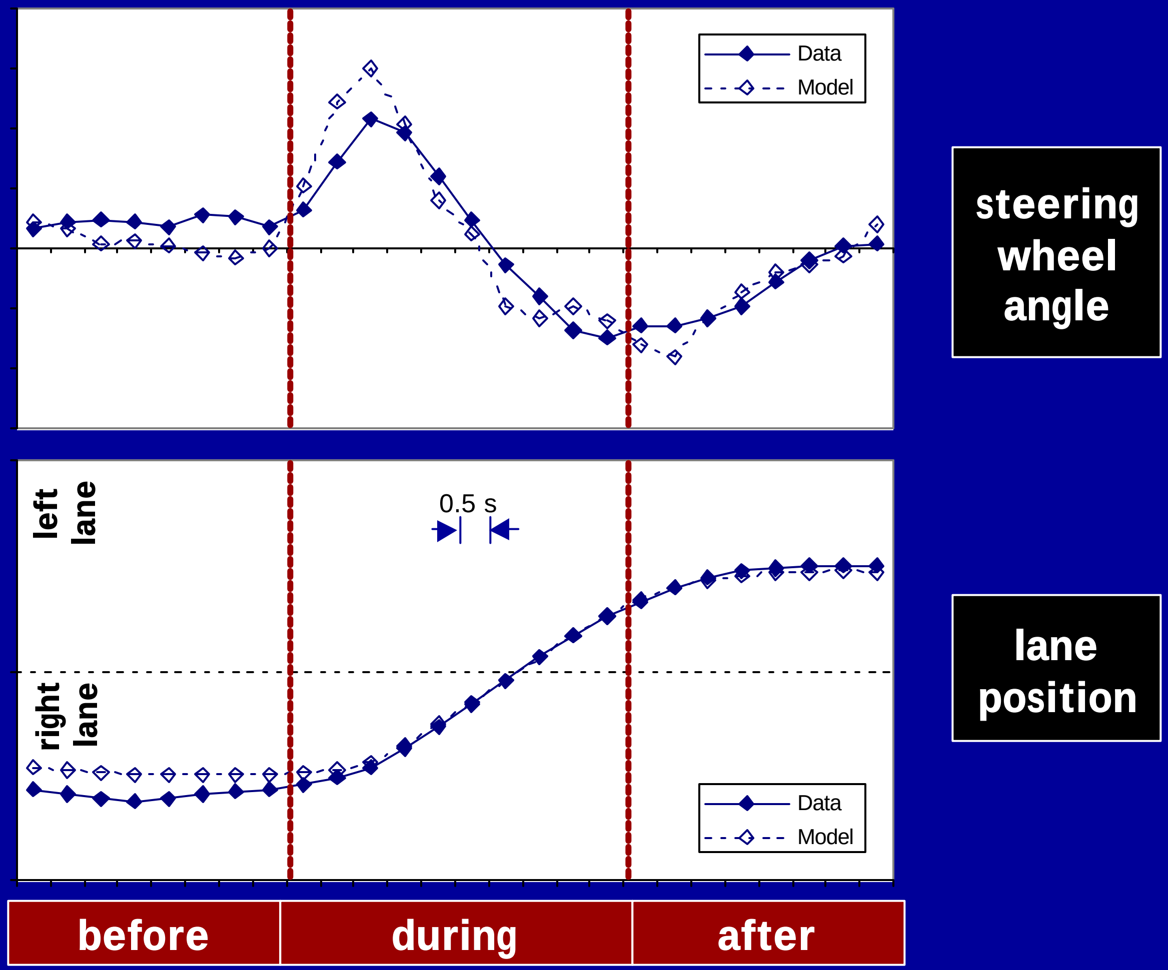
Result: Steering & Curve Negotiation

- How do drivers steer around curves?



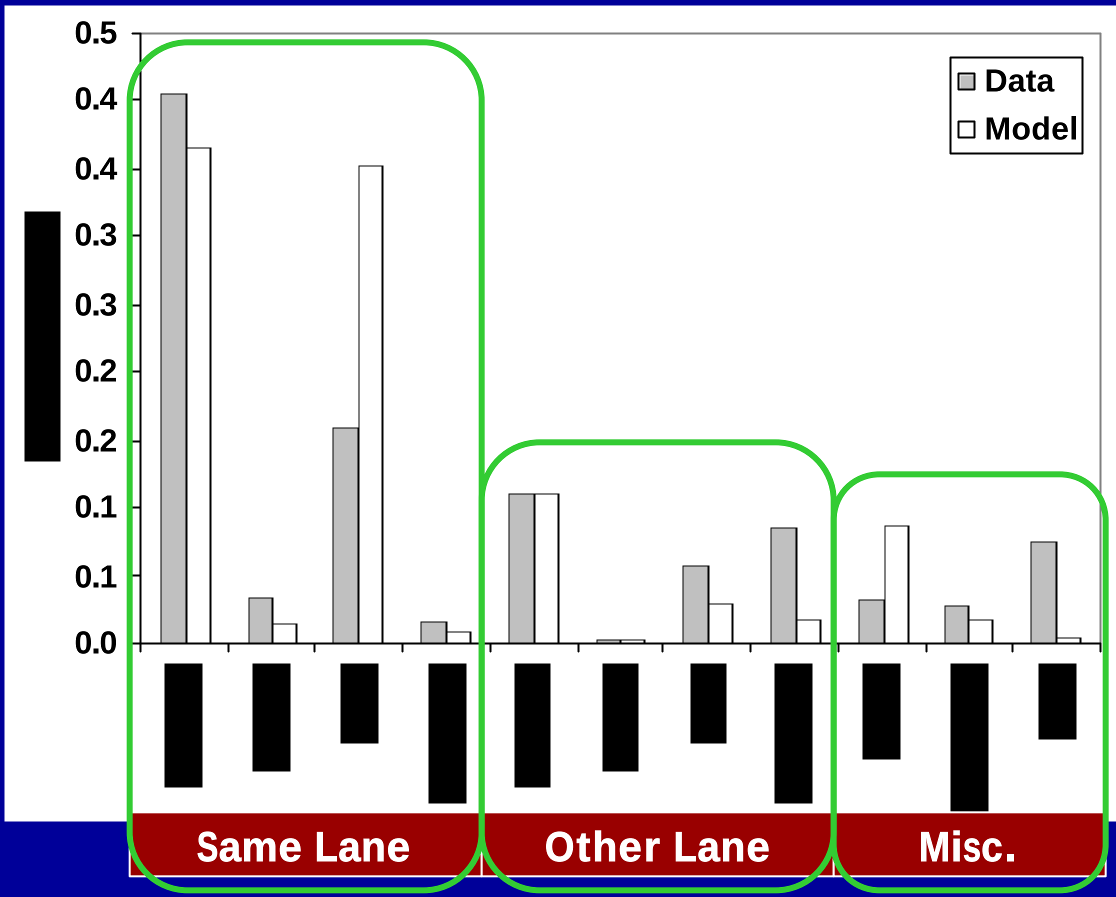
Result: Steering & Lane Changing

- How do drivers steer through a lane change?



Result: Attention & Lane Keeping

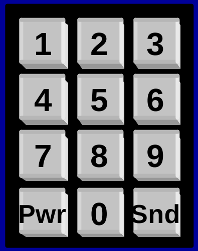
- Where do drivers look while driving?

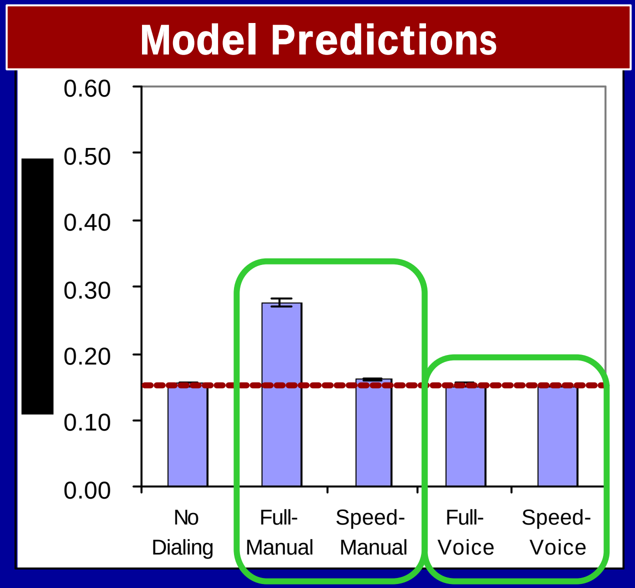


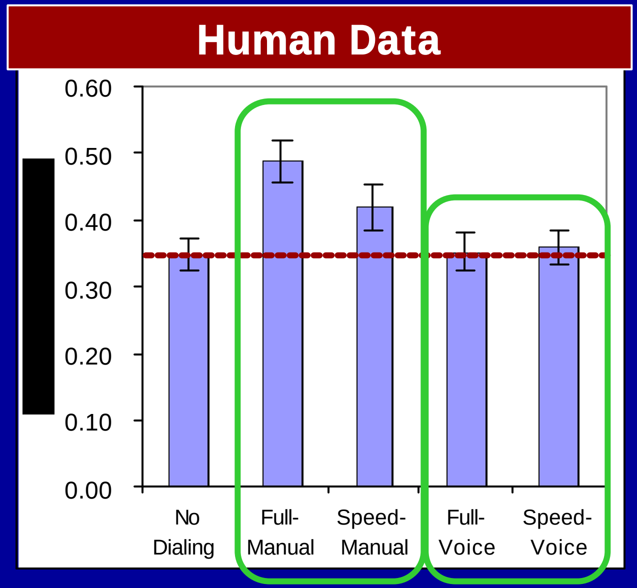
gaze dwell ratios

Result: Effects of Workload

- How do secondary tasks affect driving?
- Four possible hands-free cell phones
  - full-manual
  - speed-manual
  - full-voice
  - speed-voice







lateral deviations (RMSE) while dialing

Major ACT-R Issues

- Conversion to ACT-R 5.0
  - should happen in the next few months
- Multitasking / task scheduling
  - e.g., monitoring, secondary tasks
- Perceptual-motor modules
  - perception: 3D? motion?
  - action: steering / pedaling modules?
- Production time (effort)
  - model requires 10ms instead of default 50ms
  - Mike B: composition of complex behaviors?

On My Wish List…

- Easy-to-use environment for generating useful predictions with the driver model
- Sample scenario
  - specify a GOMS model for a new cell phone device, → translate to interact with ACT-R
  - specify individual driver parameters (e.g., age) and driver state (e.g., fatigue, alcohol) → translate to ACT-R parameters
  - run the simulation to generate *a priori* predictions of behavior — e.g., to test for driver distraction

A Symbiotic Relationship

- The driving domain will help inform and evaluate ACT-R for complex dynamic tasks
  - real-world perception, action, multitasking, …
  - *a priori* predictions (!!)
- ACT-R can (and will ☺) have a significant practical impact in the driving domain
  - Driver Intentions: ACT-R can help infer intentions
  - Driver Distraction: ACT-R can help save lives (!?)